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**Measurements of Radiofrequency Field
Intensity in Buildings with Close
Proximity to Broadcast Stations**

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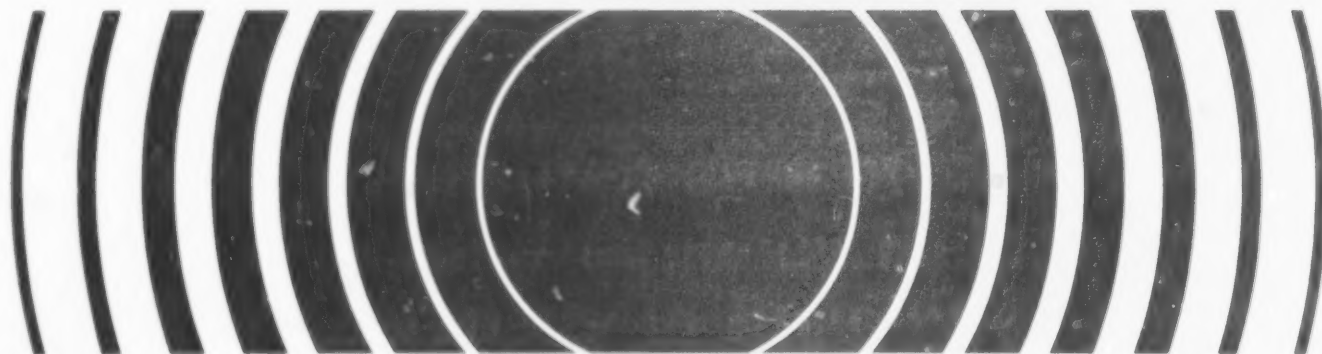
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This report summarizes the results of a series of radiofrequency field intensity measurements made in eight tall buildings located in New York, Miami, Chicago, San Diego, and Houston. The buildings, in which the measurements were made, were selected because of their proximity to FM radio and/or VHF and UHF television transmitting antennas. These broadcast antennas were usually located on nearby buildings so that the possibility existed for high intensity illumination of the upper floors of the buildings selected by the main beam of radiation of the antennas. The principal objective in conducting these measurements was to obtain information about the field intensities which can be produced by broadcast antennas at locations close to the antennas and near the main beam axis. In addition, the measurements help in determining the higher level radiofrequency exposures of persons who work and live in tall buildings under similar irradiation situations, and in developing techniques which allow estimates to be made of exposures under such conditions.

The maximum power densities derived from electric field intensity measurements in any of the eight buildings were less than 100 microwatts per square centimeter ($\mu\text{W}/\text{cm}^2$). Higher exposures were observed at unobstructed locations on roofs of some of the buildings. Observations about factors which were found to affect exposure levels are discussed.

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MEASUREMENTS OF RADIOFREQUENCY FIELD INTENSITY IN BUILDINGS
WITH CLOSE PROXIMITY TO BROADCAST STATIONS

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August 1978

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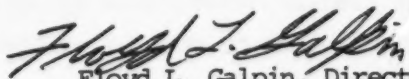
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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation, and to promote development of controls necessary to protect the public health and safety. This report describes a series of measurements of radiofrequency field intensities performed in several tall buildings that are located adjacent to high power broadcast facilities to assess exposure of individuals living or working in these situations. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.



Floyd L. Galpin, Director
Environmental Analysis Division
Office of Radiation Programs

ABSTRACT

This report summarizes the results of a series of radiofrequency field intensity measurements made in eight tall buildings located in New York, Miami, Chicago, San Diego, and Houston. The buildings, in which the measurements were made, were selected because of their proximity to FM radio and/or VHF and UHF television transmitting antennas. These broadcast antennas were usually located on nearby buildings so that the possibility existed for high intensity illumination of the upper floors of the buildings selected by the main beam of radiation of the antennas. The principal objective in conducting these measurements was to obtain information about the field intensities which can be produced by broadcast antennas at locations close to the antennas and near the main beam axis. In addition, the measurements help in determining the higher level radiofrequency exposures of persons who work and live in tall buildings under similar irradiation situations, and in developing techniques which allow estimates to be made of exposures under such conditions.

The maximum power densities derived from electric field intensity measurements in any of the eight buildings were less than 100 microwatts per square centimeter ($\mu\text{W}/\text{cm}^2$). Higher exposures were observed at unobstructed locations on roofs of some of the buildings. Observations about factors which were found to affect exposure levels are discussed.

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INTRODUCTION

This report describes the results of a series of measurements of radio-frequency (RF) field intensities made in eight different tall buildings located in five large United States cities. The measurements were made for the purposes of (1) determining the RF field intensities close to broadcast antennas near the main beam axis so that analytical techniques may be developed to allow estimates of field intensities for such exposure situations, and (2) determining the higher level general population RF exposure which can exist for persons who live or work in tall buildings situated close to high power FM radio and television transmitting installations. These buildings, due to their height and locations, have the upper parts of their structure illuminated by the main beam of radiation from the transmitting antennas.

In each instance the measurements were conducted in conjunction with a general, ground level RF survey of the given metropolitan area. The cities, buildings in which measurements were made, locations of the major broadcast transmitters, and the date of the measurements are summarized in Table 1. In all but two of the eight buildings involved in these measurements there was a high power broadcast antenna in the immediate vicinity. In measurements at the Empire State Building, the exposure levels measured were due to antennas mounted on the building itself. In measurements at the other buildings, the exposures measured were primarily due to radiation from antennas mounted on buildings other than the ones involved in the measurements.

TABLE 1. BUILDING MEASUREMENT SUMMARY

City	Building in Which Measurements were Made	Location of Primary Transmitters	Transmitters	Date of Measurement
Miami	One Biscayne Tower	100 Biscayne Boulevard	WTMI-FM	February 1976
New York	Empire State Building Pan Am Building World Trade Center South Tower	Empire State Building	Many	August 1976
Chicago	Sears Tower	(1) Chicago Board of Trade (2) 105 W. Adams	WCIU-TV(26) WBEZ-FM	September 1976
San Diego	Home Tower	Bank of America Bldg.	KITT-FM	May 1977
Houston	Milam Building	(1) Tenneco Building (2) One Shell Plaza	KLEF-FM KVRL-TV(26)	September 1977

Building Measurement Results

The results of the measurements for all of the buildings listed in Table 1 are summarized in terms of far field equivalent power density. The results, presented in Table 2, are the power densities, derived from the measurements of electric field intensities, existing at each measurement location. Power densities due to FM radio and television broadcast bands are shown individually in addition to the total combined power density for these bands.

The measurement data taken provided much more detail than appears in the summary presented in Table 2. In most of the measurements, the electric field intensities and power densities were obtained for each contributing FM radio or television station. In the case of FM radio transmission, many of the measurements specified the electric field intensities and power density associated with radiation transmission for both the horizontal and vertical polarization planes. The descriptions of building measurements for each city and location, and a much more detailed presentation of measurement results are presented in the following sections of this report.

TABLE 2. SUMMARY - POWER DENSITIES FOR ALL BUILDING MEASUREMENTS

City	Measurement Location	Power Density FM Radio ($\mu\text{W}/\text{cm}^2$)	Power Density Television ($\mu\text{W}/\text{cm}^2$)	Total Power Density ($\mu\text{W}/\text{cm}^2$)
New York	Empire State Building 86th floor observatory (outside)	15.2	-	15.2
	102nd floor observatory (inside)	30.7	1.79	32.5
	Near Window	1.35	-	1.35
	Near Elevator			
	World Trade Center			
Miami	South Tower			
	107th floor observatory	0.10	1.10	1.20
	Roof	0.15	7.18	7.33
	Pan Am Building			
	54th floor	3.76	6.52	10.3
	One Biscayne Tower			
	26th floor	6.69	-	6.69
	30th floor	5.24	-	5.24
	34th floor	62.1	-	62.1
	38th floor	96.8	-	96.8
Chicago	Roof - partially shielded area	134	-	134
	Roof - open area	148	-	148
	Sears Building			
	50th floor - near window	31.7	34.2	65.9
	Roof	201	29.0	230
San Diego	Federal Building			
	39th floor	5.74	.730	6.47
	Home Tower			
	10th floor	18	-	18
Houston	17th floor	0.22	-	0.22
	Roof location 1	180.3, 126*	-	180.3
	Roof location 2	119.0, 162*	-	119.0
	1100 Milam Building			
	47th floor	35.8	31.6	67.4

*Measured with the NBS probe EDM-3.

Measurement Technique

The measurements of electric field intensity in buildings were performed with an instrumentation system consisting of a tuned half-wave dipole receiving antenna connected through coaxial attenuators to a scanning spectrum analyzer. Signal amplitudes, representing power received by the antenna, were measured with the spectrum analyzer and corrected for signal attenuation and antenna calibration factors to obtain incident electric field intensity. The set of Singer tunable dipole antennas used in the measurements had been previously calibrated by referencing them to a set of National Bureau of Standards calibrated dipoles. A detailed description of this calibration process is available elsewhere (Tell, et al., 1976). Figure 1 provides the dipole antenna factor as a function of frequency for the Singer dipoles used. The maximum deviation of the fitted calibration curve from measured data is 1.3dB. The spectrum analyzer was a Tektronix model 7L13.

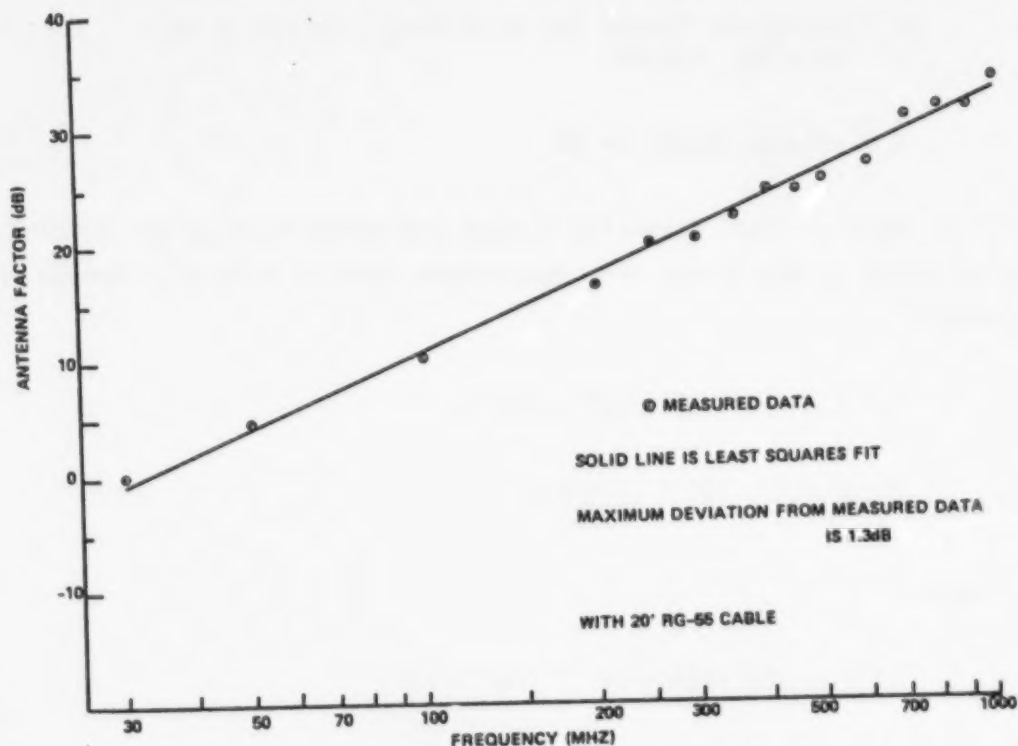


Figure 1. Singer dipole calibration data

The data processing procedure consisted of: (1) correcting the measured power (in dBm), as indicated by the spectrum analyzer, for any external attenuation which may have been used for instrument protection; (2) conversion of the power reading (in dBm) to a voltage produced in the 50Ω system (dB μ V), and (3) adding the appropriate antenna factor to determine the electric field intensity incident on the antenna. In effect, the electric field strength is defined by:

$$E(\text{dB}\mu\text{V/m}) = P(\text{dBm}) + 107 + A(\text{dB})$$

where:

E = electric field intensity in dB μ V/m

P = power detected from antenna in dBm

107 = conversion factor for converting from dBm to dB μ V
in a 50Ω system

A = antenna factor in dB

The electric field intensity is then expressed in units of volts/meter and converted to equivalent free space power density $S(\mu\text{W}/\text{cm}^2)$ through the relations:

$$E(\text{V/m}) = 10 \text{ Exp}[E(\text{dB}\mu\text{V/m})/20-6]$$

$$S(\mu\text{W}/\text{cm}^2) = 100 \times \frac{[E(\text{V/m})]^2}{377\Omega}$$

where:

377Ω is the impedance of free space

In addition to measurements made with the spectrum analyzer and tuned dipoles, measurements were made in San Diego and Houston using the National

Bureau of Standards hazard survey probe EDM-3. The EDM-3 measures the electric field energy density, U_E . Electric field energy density is a meaningful measure of the RF intensity in the near field of an antenna and is superior to the parameter power density, the values of which can be erroneous when applied to the near field. The measured electric field energy density, U_E , can be related to the far field power density, S , by the relation

$$S(\mu W/cm^2) = 60U_E(nJ/m^3)$$

where electric field energy density, U_E , is expressed in units of nanojoules per cubic meter (nJ/m^3). Alternatively, the square of the electric field strength, E , expressed in units of volts squared per meter squared (V^2/m^2) is related to the electric field energy density by the relation

$$E^2(V/m)^2 = \frac{2 \times 10^{-9} U_E(nJ/m^3)}{\epsilon_0(F/m)}$$

where ϵ_0 is the permittivity of free space and is equal to 8.854×10^{-12} farads/meter (F/m). The units of V^2/m^2 are used as another method of quantifying the exposure in the near field as provided for in the American National Standards Institute (ANSI) standard C95.1 - 1974. This unit is related directly to the measured electric field energy density without assumptions about the relationship between the electric and magnetic field components. A technical description of the EDM-3 has been given by Tell and O'Brien (1977), in relation to work in the vicinity of FM and TV transmitters, and by Bowman (1974).

BUILDING MEASUREMENTS

New York

Measurements of electric field intensity were made at the Empire State Building inside the 102nd floor observatory and outside on the 86th floor observatory, at the World Trade Center - South Tower inside the 107th floor observatory and on the roof, and at the Pan Am Building in a 54th floor office. Virtually all FM radio and television (TV) stations in New York City presently transmit from the top of the Empire State Building. Measurement locations were chosen at the World Trade Tower and the Pan Am Building that allowed direct line of sight paths to the Empire State Building. Tables 3 and 4 list the FM radio and TV stations whose signals were monitored during these measurements. Fifteen FM radio and seven TV stations transmit from the Empire State Building.

The 102nd floor observatory of the Empire State Building is a unique location in that, besides being a popular tourist attraction, a unique double-ring array of FM dipole elements, diplexed to 11 FM stations simultaneously, is affixed to the exterior of the building with the upper ring of dipoles being approximately four feet from the glass windows of the observatory. The observatory windows are coated with a special electrically conductive film for the purpose of significantly attenuating the radiofrequency fields which propagate into the observatory area. This attenuation was apparent in that the measured electric field intensities inside the observatory were much lower than would be expected if there were no attenuating film on the windows.

The results of the measurements at the five building locations are presented in Tables 5-8. The electric field intensity and power density contribution for each FM radio and TV station are presented in addition to

TABLE 3. NEW YORK FM RADIO STATIONS CONTRIBUTING TO MEASURED LEVELS

Station	Frequency (MHz)	EPR (kW) ¹		HAAT ² (Ft)
		Horizontal Plane	Vertical Plane	
*WKTU-FM	92.3	5.4	3.8	1220
WPAT-FM	93.1	12.5	12.5	870
*WNYC-FM	93.9	5.3	3.8	1220
*WPLJ-FM	95.5	4.6		1300
*WQXR-FM	96.3	5.4	3.8	1220
*WNWS-FM	97.1	3.6		1450
*WEVD-FM	97.9	5.3	3.8	1220
*WXLO-FM	98.7	5.4	3.8	1220
*WBAI-FM	99.5	5.4	3.85	1220
*WCBS-FM	101.1	4.6		1330
*WPIX-FM	101.9	5.4	3.8	1220
*WNEW-FM	102.7	4.1		1360
*WNCN-FM	104.3	5.4	3.8	1220
*WRFM-FM	105.1	5.4	3.7	1220
*WRVR-FM	106.7	5.4	3.8	1220
*WBLS-FM	107.5	2.0	1.45	1220

*Indicates stations transmitting from Empire State Building.

¹Effective radiated power (kilowatts) in horizontal and vertical polarization planes; single entry indicates horizontal polarization only.

²Height above average terrain.

TABLE 4. NEW YORK TV STATIONS¹ CONTRIBUTING TO MEASURED LEVELS

Station	Channel	ERP (kW)		HAAT (Ft)
		Visual Carrier	Aural Carrier	
WCBS	2	42.0	8.32	1300
WNBC	4	30.2	5.13	1440
WNEW	5	37.1	5.5	1330
WABC	7	110	11	1465
WOR	9	155	31	1240
WPIX	11	100	19.5	1410
WNET	13	25.3	5.36	1200

¹All stations are located on the Empire State Building.

TABLE 5. EMPIRE STATE BUILDING-MEASURED ELECTRIC FIELD INTENSITIES

Station	86th Floor Observatory		102nd Floor Observatory			
	E(V/m)	S(μ W/cm ²)	Near Window		Center of Room	
			E(V/m)	S(μ W/cm ²)	E(V/m)	S(μ W/cm ²)
WKTU-FM	2.25	1.35	3.78	3.80	0.95	0.24
WPAT-FM	0.12	0.0038	-	-	-	-
WNYC-FM	2.13	1.20	4.01	4.26	0.75	0.15
WPLJ-FM	0.30	0.024	-	-	-	-
WQXR-FM	2.25	1.35	4.01	4.26	0.30	0.024
WNWS-FM	0.19	0.0095	-	-	-	-
WEVD-FM	2.13	1.20	3.37	3.02	0.80	0.17
WXLO-FM	2.53	1.70	3.78	3.80	0.95	0.24
WBAI-FM	2.68	1.90	3.78	3.80	0.95	0.24
WCBS-FM	0.43	0.048	-	-	-	-
WPIX-FM	2.53	1.70	3.01	2.40	0.75	0.15
WNEW-FM	0.95	0.24	-	-	-	-
WNCN-FM	2.39	1.51	2.39	1.51	0.45	0.054
WRFM-FM	2.39	1.51	2.39	1.51	0.43	0.048
WRVR-FM	1.90	0.95	2.53	1.70	0.30	0.024
WBLS-FM	1.34	0.48	1.60	0.68	0.15	0.006
WOR-TV(9)						
Visual	-	-	1.97	1.03	-	-
Audio	-	-	0.70	0.13	-	-
WNET-TV(13)						
Visual	-	-	1.26	0.42	-	-
Audio	-	-	0.89	0.21	-	-
Total Power Density (μ W/cm ²)						
FM		15.2		30.7		1.35
TV		-		1.79		-

TABLE 6. WORLD TRADE CENTER
MEASURED ELECTRIC FIELD INTENSITIES FROM FM RADIO

Station	107th Floor ^a Observatory			Roof Observatory		
	E(V/M)		S(μ W/cm ²)	E(V/m)		S(μ W/cm ²)
	Horizontal	Vertical		Horizontal	Vertical	
WKTU-FM	0.16	0.06	.0077	0.10	0.17	.010
WPAT-FM	0.10	0.08	.0042	0.15	0.27	.025
WNYC-FM	0.13	0.05	.0056	0.10	0.10	.0051
WPLJ-FM	0.12	0.06	.0048	0.13	0.13	.0096
WQXR-FM	0.17	0.07	.0090	0.14	0.15	.011
WNWS-FM	0.13	0.04	.0052	0.12	0.01	.0038
WEVD-FM	0.27	0.11	.022	0.15	0.12	.0098
WXLO-FM	0.24	0.08	.017	0.16	0.13	.012
WBAI-FM	0.17	0.08	.0095	0.13	0.11	.0077
WCBS-FM	0.27	0.04	.019	0.08	0.15	.0079
WPIX-FM	0.08	0.05	.0021	0.17	0.15	.014
WNEW-FM	0.04	0.08	.0018	0.16	0.13	.012
WNCN-FM	0.05	0.05	.0014	0.12	0.11	.0068
WRFM-FM	0.07	0.04	.0016	0.13	0.13	.0096
WRVR-FM	0.05	0.04	.0011	0.13	0.11	.0078
WBLS-FM	0.02	0.03	.00032	0.07	0.05	.0020
Total S(μ W/cm ²)			.11			.15

TABLE 7. WORLD TRADE CENTER
MEASURED ELECTRIC FIELD INTENSITIES FROM TELEVISION

Station	107th Floor Observatory		Roof Observatory	
	E(V/m)	S(μ W/cm ²)	E(V/m)	S(μ W/cm ²)
WCBS (2)				
Visual Carrier	0.06	.00095	0.22	0.013
Aural Carrier	0.35	.032	0.10	0.0026
WNBC (4)				
Visual Carrier	0.72	.14	0.19	0.0096
Aural Carrier	0.10	.0026	0.09	0.0019
WNEW(5)				
Visual Carrier	0.78	.16	0.66	0.11
Aural Carrier	0.22	.013	0.35	0.032
WABC (7)				
Visual Carrier	0.93	.23	2.94	2.30
Aural Carrier	0.37	.036	0.70	0.13
WOR (9)				
Visual Carrier	0.78	.16	2.21	1.29
Aural Carrier	0.49	.065	1.80	0.86
WPIX (11)				
Visual Carrier	0.94	.23	1.67	0.74
Aural Carrier	0.30	.023	0.84	0.19
WNET (13)				
Visual Carrier	*	*	2.24	1.33
Aural Carrier			0.80	0.17
Total S(μ W/cm ²)		1.09		7.18

*Not measured

TABLE 8. PAN AM BUILDING
MEASURED ELECTRIC FIELD INTENSITIES, 54TH FLOOR

FM Radio				Television		
Station	E(V/m)		S(μ W/cm ²)	Station	E(V/m) S(μ W/cm ²)	
	Horizontal	Vertical				
WKTU-FM	1.07	0.60	0.40	WCBS (2)		
WPAT-FM	0.30	0.34	0.054	Visual	1.10	0.32
WNYC-FM	0.75	0.42	0.20	Aural	0.78	0.16
WPLJ-FM	0.60	0.24	0.11	WNBC (4)		
WQXR-FM	1.13	0.42	0.38	Visual	0.68	0.12
WNWS-FM	0.38	0.03	0.038	Aural	0.30	0.024
WEVD-FM	1.13	0.48	0.40	WNEW (5)		
WXLO-FM	1.34	0.60	0.57	Visual	1.75	0.81
WBAI-FM	1.20	0.48	0.44	Aural	0.87	0.20
WCBS-FM	0.36	0.15	0.040	WABC (7)		
WPIX-FM	1.20	0.38	0.42	Visual	0.93	0.23
WNEW-FM	0.60	0.38	0.13	Aural	0.42	0.046
WNCN-FM	0.75	0.19	0.16	WOR (9)		
WRFM-FM	0.75	0.17	0.16	Visual	3.12	2.57
WRVR-FM	0.85	0.05	0.19	Aural	1.56	0.65
WBLS-FM	0.48	0.05	0.061	WPIX (11)		
				Visual	1.33	0.47
				Aural	0.21	0.012
				WNET (13)		
				Visual	1.78	0.84
				Aural	0.50	0.067
Total S			3.76			6.52

the total power density determined at each measurement location. Measurements in the FM band were made with the dipole antenna adjusted for the frequency at the center of the FM band, i.e., 98 MHz. The individual signals produced by each FM station could be viewed on the spectrum analyzer CRT in the scan of the FM band. Measurements in the Empire State Building were performed with the antenna oriented to obtain generally maximized signals for the entire group of FM stations. Separate measurements (in the FM band) were made of the horizontal and vertical components of electric field intensity at the World Trade Center and the Pan Am Building. A single azimuthal orientation of the dipole antenna in the horizontal plane was sufficient to yield a maximum response for the horizontal plane component.

Several observations from these results are pertinent. The maximum exposure level was found in the 102nd floor observatory of the Empire State Building and was $32.5 \mu\text{W}/\text{cm}^2$ for the stations measured; almost all of this is due to the adjacent FM transmitting antenna array mounted near the windows. Exposure from all FM and VHF-TV stations in the 107th floor observatory of the World Trade Center was $1.2 \mu\text{W}/\text{cm}^2$, and on the roof of the World Trade Center the corresponding exposure was $7.3 \mu\text{W}/\text{cm}^2$; in both cases the TV signals accounted for the principal part of the total exposure. Total exposure from all FM and VHF-TV stations in the 54th floor office in the Pan Am Building was $10.3 \mu\text{W}/\text{cm}^2$, with the contribution from television transmission being greater.

The effect of antenna radiation pattern on exposure situations can be seen from the measurements made at the buildings in New York. The 86th floor measurements at the Empire State Building were made below the FM dipole array and the television antennas, and outside of the building where walls, ceilings, and roofs would not act to attenuate the radiation levels. Measurements made at the World Trade Center and Pan Am Building were made in the main beam of the television antennas located on the Empire State Building; the measurement locations at the World Trade Center being close to the maximum intensity of the main beam. A comparison of the TV measurements shows very little power transmitted in a downward direction as compared to power transmission in the forward direction. Electric field intensity due to TV transmission (in the downward direction) at the 86th floor of the Empire State Building was negligible, while at the Pan Am Building and the World Trade Center the electric field

intensity, due to TV transmission in the horizontal direction, levels were much greater even though these buildings are much more distant from the sources.

Although the total power transmitted in the FM radio band by the Empire State Building antennas is much less than that for television transmission, the field intensity (and power density) measured on the 86th floor observatory is significant and much greater than that due to TV transmission. This shows that significantly more power is radiated in the downward direction from the FM antennas than for the TV antennas, i.e., the TV antenna radiation patterns are more directional than those of the FM antennas. Power densities due to the FM transmission at the World Trade Center and Pan Am Building, also due to main beam exposure are less than those due to TV transmission because of the lower power of the FM stations. All of the summarized results of the building measurements in New York are included in Table 2.

The electric field intensities (and associated power densities) measured in the Empire State Building's 102nd floor observatory would be much greater if the observatory windows were not coated with the electrically conductive film used to attenuate the electric fields produced by the FM antenna array just outside of the observatory. The attenuating effects of the film on the intensity of the electric field associated with FM radio transmission can be estimated by comparing typical measured field intensities to that which would be expected to exist if the film was not present. The possible range of attenuation is estimated by using in the comparisons two FM stations (using the dipole array) of equal effective radiated power near the extremes of the FM radio band.

This appears to be a reasonable approach suggested by the measured electric field intensities shown in Table 5. Of the eleven FM stations which are diplexed to the dipole array, ten have total effective radiated power (ERP) of approximately 9.2 kW (Table 2). Generally, the measured

electric field intensities decrease as the radiation frequency increases, indicating a possible variation in attenuation of the coated window as a function of frequency. Therefore, WNYC-FM, at 93.9 MHz and producing a measured field intensity of 4.01 V/m, and WRFM-FM, at a frequency of 105.1 MHz and having a measured field intensity of 2.39 V/m, are taken to represent the extremes in measured field strength and frequency.

The diplexed dipole array consists of 2 rings of 16 dipoles each, placed at locations equidistant from one another around the circumference of the observatory. Each dipole element transmits radiation for all FM stations, and each transmits equal amounts of power; i.e., each of the ten FM stations of 9.2 kW ERP can be considered to radiate 1/32 of that from each dipole element. Thus each element is considered to transmit with an ERP of 288 watts for each of the ten FM stations involved. The distance between the nearest transmitting dipole element and the measurement antenna is assumed to be 3 meters. At this distance, the electric field strength produced by a half wave dipole transmitting with an ERP of 1 watt is calculated to be 2 V/m. Consequently, for the dipole with an ERP equal to 288 watts, a field of 33.9 V/m would be produced at 3 meters if there was no attenuation. The ratio between the measured field intensity of 4.01 V/m and the theoretical field intensity of 33.9 V/m is 0.118, or -18.5 dB. A comparison of the measured and calculated unattenuated field intensity at the upper end of the frequency band yields a reduction factor of -23.0 dB.

Miami

Measurements of radiofrequency electric field intensities due to the operation of an FM radio station, were made at several locations in a 40 story Miami office building, One Biscayne Tower. The building is located very close to the transmitting antenna of WTMI-FM, 93.1 MHz and 120 kW, which is atop a nearby 30 story building at 100 Biscayne Boulevard. The roof of One Biscayne Tower is higher than the WTMI antenna. The upper floors of the building are exposed to main beam radiation.

Measurements were made at locations on the north side of the building, where a direct view of the WTMI antenna exists from several floors. This situation permits field intensity determinations, at several different locations, to generally describe the vertical radiation pattern of the transmitting antenna. Field intensity measurements were made on the 26th, 30th, 34th, and 38th floors, and the roof. Measurements were confined to vacated areas, not yet occupied at the time. Venetian blinds were raised to assess maximum possible exposure levels. Typical levels if the blinds were lowered and closed would be expected to be significantly lower than those measured. Measurements were made in both the horizontal and vertical polarization planes, and the corresponding far field equivalent power densities determined. The results of the measurements are tabulated in Table 9.

The maximum power density determined from measurements inside of the building was $96.8 \mu\text{W}/\text{cm}^2$ on the 38th floor. Measurements were made of the intensity of the WTMI-FM signal alone since, at the time of measurement, this signal was by far the strongest of all being received in the building. The contribution of other signals present was not determined, but would be expected to increase the levels measured only slightly.

TABLE 9. ONE BISCAYNE TOWER
MEASUREMENTS OF ELECTRIC FIELD INTENSITIES FROM WTMI-FM*

Measurement Location	E(dB μ V/m)		E _{total} (V/m)	S(μ W/cm ²)
	Horizontal	Vertical		
26th floor	124.5	133.5	5.02	6.68
30th floor	127.5	131.5	4.44	5.24
34th floor	137.5	142.5	15.3	62.1
38th floor	141.5	143.5	19.1	96.8
Roof - partially shielded area	143.5	144.5	22.49	134.1
Roof - open area	140.5	146.5	23.64	148.2

*WTMI transmits at a frequency of 93.1 MHz and with an ERP of 120 kW.

Chicago

Radiofrequency field intensities were measured inside a 50th floor office and on the roof of the Sears Tower, and inside a 39th floor office of the Federal Building. These two buildings were selected because of their proximity to two nearby broadcasting stations, WBEZ-FM which transmits at 91.5 MHz with an ERP of 39 kW, and WCIU which transmits at 542 to 548 MHz with an ERP of 1155 kW. The Sears Tower 50th floor office faced both WCIU-TV (Channel 26) and WBEZ-FM, and appeared to be approximately at the height of the centers of radiation for both antennas. The 39th floor office of the Federal Building is nearest to WBEZ-FM, but below the main beam of radiation.

Table 10 summarizes the FM band field intensity data and the total far-field equivalent power density at the Sears Tower 50th floor office. The total power density measured due to FM radio was $31.7 \mu\text{W}/\text{cm}^2$ with WBEZ contributing $31.3 \mu\text{W}/\text{cm}^2$. The stations are not identified by call letters or frequency in Table 10. Measurements of FM fields at one location on the roof of the Sears Tower, presented in Table 11, show that four FM stations are the major contributors to a total power density due to FM radio transmission, of $200.8 \mu\text{W}/\text{cm}^2$. Four FM stations have their antennas mounted on the West Tower of the Sears Building and these are the ones included in Table 11. WBEZ-FM is not a contributor to the field intensity existing on the roof, since the WBEZ antenna is hundreds of feet below the level of the roof.

Table 12 provides the results of field measurements for the television broadcast band. WCIU (26) was responsible for most of the far-field equivalent power density measured on the 50th floor, contributing $33.2 \mu\text{W}/\text{cm}^2$ toward a total of $34.2 \mu\text{W}/\text{cm}^2$ for all of the TV channels measured. It is only a minor contributor to the total power density, $29 \mu\text{W}/\text{cm}^2$, at the roof location due to TV transmission. Two of the major contributors, WLS (7) and WTTW (11) are located on the West Tower of the Sears Building. The other TV stations are located on the roof of the Hancock Building, roughly 1 mile distant and at a height which places them above the levels of the Sears Tower roof.

Table 13 presents the results of measurements made in a 39th floor office of the Federal Building. The power density contributions from TV and FM bands are $0.73 \mu\text{W}/\text{cm}^2$ and $5.74 \mu\text{W}/\text{cm}^2$, respectively, with the primary contributors being WCIU (26) and WBEZ-FM.

The measurements were made under conditions which attempted to maximize the power density existing at the windows of the offices in the Sears Tower and the Federal Building; i.e., the blinds were raised, and measurements were made near the windows. The levels measured would be expected to be significantly reduced if the blinds had been lowered and closed.

TABLE 10. SEARS TOWER
MEASURED ELECTRIC FIELD INTENSITIES FROM FM RADIO; 50TH FLOOR OFFICE

Station Index	E(V/m)		E _{total} (V/m)	S(μ W/cm ²)
	Horizontal	Vertical		
1	0.012	0.027	.0295	0.00023
2	0.015	0.013	.0203	0.00011
3	0.054	0.076	.0929	0.0023
4	0.17	0.060	.178	0.0084
5	0.24	0.043	.244	0.016
6	0.27	0.060	.276	0.020
7	0.12	0.17	.208	0.011
8	0.43	0.12	.443	0.052
9	0.60	0.19	.632	0.11
10	0.27	0.12	.295	0.023
11	0.24	0.095	.258	0.018
12	0.24	0.060	.247	0.016
13	0.068	0.054	.0863	0.0020
14	0.27	0.076	.280	0.021
15	0.095	0.060	.113	0.0034
16	0.17	0.076	.186	0.0092
17	0.30	0.085	.314	0.026
18	0.034	0.043	.0545	0.00079
19	0.0043	0.0024	.00489	0.0000064
20	0.19	0.085	.209	0.012
21	0.054	0.048	.0719	0.0014
22	6.76	8.51	10.9	31.3
Total S(μ W/cm ²)				31.7

TABLE 11. SEARS TOWER
MEASURED ELECTRIC FIELD INTENSITIES FROM FM RADIO; ROOF

Station Index	E(V/m)		E _{total} (V/m)	S(μ W/cm ²)
	Horizontal	Vertical		
1	11.1	9.89	14.9	58.6
2	6.24	9.89	11.7	36.2
3	7.94	9.81	11.9	37.8
4	9.12	13.2	16.0	68.2
Total S				200.8

TABLE 12. SEARS TOWER
MEASURED ELECTRIC FIELD INTENSITIES FROM TELEVISION

Station	50th Floor Office		Roof	
	E(V/m)	S(μ W/cm ²)	E(V/m)	S(μ W/cm ²)
WBBM (2)				
Visual Carrier	0.78	0.16	0.22	0.013
Aural Carrier	0.87	0.20	0.25	0.016
WMAQ (5)				
Visual Carrier	0.62	0.10	0.55	0.080
Aural Carrier	0.19	0.010	0.19	0.010
WLS (7)				
Visual Carrier	0.082	0.0018	9.23	22.6
Aural Carrier	0.073	0.0014	1.64	0.71
WGN (9)				
Visual Carrier	0.87	0.20	0.98	0.25
Aural Carrier	0.28	0.020	0.28	0.020
WTTW (11)				
Visual Carrier	0.030	0.00023	2.09	1.16
Aural Carrier	0.030	0.00023	1.17	0.37
WCIU (26)				
Visual Carrier	10.0	26.5	0.63	0.11
Aural Carrier	5.01	6.66	0.20	0.011
WFLD (32)				
Visual Carrier	0.96	0.24	1.78	0.84
Aural Carrier	0.48	0.061	0.54	0.076
WSNS (44)				
Visual Carrier	0.34	0.031	3.05	2.48
Aural Carrier	0.27	0.020	1.08	0.31
Total S		34.2		29.0

TABLE 13. FEDERAL BUILDING (39TH FLOOR OFFICE)
MEASURED ELECTRIC FIELD INTENSITIES - TV AND FM

Station	E(V/m)		S(μ W/cm ²)
	Visual	Aural	
TV			
WBBM (2)	0.14	0.078	0.0067
WMAQ (5)	0.062	0.025	0.0012
WLS (7)	0.18	0.082	0.011
WGN (9)	0.062	0.035	0.0013
WTTW (11)	0.066	0.052	0.0019
WCIU (26)	1.58	0.40	0.71
WFLD (32)*			
WSNS (44)*			
Total S			0.73
FM	Horizontal	Vertical	
#1	3.51	2.51	4.56
#2	0.62	0.14	0.11
#3	1.12	0.25	0.35
#4	1.29	1.02	0.72
Total S			5.74

*Not transmitting at time of measurement.

San Diego

Electric field intensity measurements were made in a 17th floor office of the Home Tower building in downtown San Diego. The 18 story Home Tower is directly across the street from the Bank of America Building where the transmitting antenna for KITT-FM radio is located. KITT-FM operates at a frequency of 105.1 MHz with a total effective radiated power (ERP) of 151 kW (120 kW horizontal polarization + 31 kW vertical polarization.) The west side of the Home Tower, facing the station, was estimated to be about 193 feet from the antenna through use of a street map. A distance of 207 feet was measured with an optical range finder.

The 17th floor office in the Home Tower is directly opposite the second bay (from the bottom) of the 8 bay KITT antenna. For the 200 ft. separation distance, it was expected that the power density existing at the Home Tower office would be greater than $300 \mu\text{W}/\text{cm}^2$. Instead, measurements made, using the dipole antenna and spectrum analyzer, indicated a power density of $0.211 \mu\text{W}/\text{cm}^2$, a factor of at least 1.5×10^3 , or 31.8 dB, lower than expected. Measurements made on the roof of the Home Tower, at a location about 40 to 50 feet further away because of the roof layout and with no intervening structures, yielded a total power density of $180 \mu\text{W}/\text{cm}^2$.

The NBS EDM-3, previously described, was also used for these roof measurements. A value of electric field energy density equivalent to a power density of $126 \mu\text{W}/\text{cm}^2$ was obtained, indicating a difference of + 1.6 dB between the spectrum analyzer system and the EDM-3. It was noted, using the EDM-3, that the field along the location of the dipole antenna used in this measurement, but with the dipole removed, was non-uniform. Another measurement location adjacent to the first was found at which the field, again using the EDM-3, appeared to be quite uniform over a distance that the dipole antenna would occupy. At this location, measurements made using both systems resulted in indicated power densities of $119 \mu\text{W}/\text{cm}^2$ and $162 \mu\text{W}/\text{cm}^2$ for the spectrum analyzer system and EDM-3, respectively. The relative difference in indicated power density between the spectrum analyzer system and EDM-3 was -1.3 dB. On the basis of these two sets of measurements, it is not possible to resolve the differences between the two measurement techniques.

The pertinent results of the measurements at the Home Tower are summarized in Table 14. The fact that the power density existing inside the building, $0.211 \mu\text{W}/\text{cm}^2$, was so much less than the expected value of about $320 \mu\text{W}/\text{cm}^2$, was very surprising. However, it was later found that windows on the west side of the Home Tower, starting at the 11th floor and continuing up through the 18th floor, have a metallized mylar film applied to them to reduce solar heat loading in the building.

This film, consisting of a mylar substrate coated with a thin aluminum film, reflects sufficient light to significantly reduce heat input to a building due to incident sunlight, but still retains excellent visual transparency. Being electrically conductive, it would also be expected to have RF shielding properties. Based on the measurements made in the 17th floor office and a comparison with the expected power density, it appears that the shielding effectiveness of the film may be about 30 dB. However, estimates of power densities in buildings are complicated by factors such as possible non-uniformity in the azimuthal radiation pattern of the antenna and possible shielding by the structure of a part of the RF radiation being transmitted because of the extended area of the antenna. Such RF shielding properties in a relatively inexpensive material, normally used to reduce heat loading without being opaque, suggests a possibility for an easy and inexpensive method to alleviate situations of excessive exposure levels in buildings for either persons or electronic equipment susceptible to radiofrequency interference.

TABLE 14. HOME TOWER
MEASUREMENTS OF ELECTRIC FIELD INTENSITIES FROM KITT-FM

Measurement Location	E(dB μ V/m)		E _{total} (V/m)	S(μ W/cm ²)
	Horizontal	Vertical		
17th floor	117	115	.912	.22
Roof location 1*	143	147	26.1	180.3
Roof location 2**	141	145	21.2	119.0

*NBS EDM-3 probe reading: 2.1 nJ/m³ = 126 μ W/cm².

**NBS EDM-3 probe reading: 2.7 nJ/m³ = 162 μ W/cm².

Houston

The 100 Milam Building is a high rise office building located extremely close to two other high rise buildings whose roofs support the antennas for one UHF television and nine FM radio stations. Located atop the Tenneco Building, at a measured distance of 25.6 meters from the Milam Building is the antenna of KLEF-FM, a 200 kW station. Approximately 205 meters from the Milam Building is One Shell Plaza which supports 8 high power FM radio stations and KVRL, channel 26, a 3196 kW UHF-TV station. Measurements of electric field intensity were performed in a 47th floor office area of the Milam Building facing the KLEF antenna. The measurement location is thought to be near the maximum intensity of the KLEF radiation pattern. The measurement results consisting of the individual stations and their measured contributions to the RF field intensity and power density are presented in Table 15. A total power density of $68 \mu\text{W}/\text{cm}^2$ was determined to exist at the measurement location. KLEF contributed $33.8 \mu\text{W}/\text{cm}^2$, KVRL was responsible for $31.6 \mu\text{W}/\text{cm}^2$, and the remaining eight FM radio stations on One Shell Tower together produced $2.0 \mu\text{W}/\text{cm}^2$ of the total.

It is of interest to note that the measured power density of $34 \mu\text{W}/\text{cm}^2$ produced by KLEF is 14.3 dB below the expected power density of $923 \mu\text{W}/\text{cm}^2$ which is determined by a calculation using the far-field effective radiated power (76 kW) based on transmitter power and far-field gain of the antenna. If the 12 bay, 33 meter long KLEF antenna is modeled as a vertically stacked array of half-wave dipole elements, a careful calculation of the field along the axis of the center of radiation reveals that the array exhibits significant near field gain compression at a distance of 25.6 meters, being about 15dB below the array's far field value. The modeled gain compression as a function of distance from the array is shown in figure 2. It is seen that the measurement location, 25 meters distant from the antenna, was in the near field. The measured value of gain compression, based on the comparison of measured power density and calculated far field power density, is -14.3 dB. The calculated gain compression derived from figure 2 is about -15 dB.

TABLE 15. MILAM BUILDING
MEASURED ELECTRIC FIELD INTENSITIES, 47TH FLOOR

Station	Frequency (MHz)	EPR* (kW)	E(dB μ V/m)		E(V/m)	S(μ W/cm ²)
			Horizontal	Vertical		
KLEF-FM	94.7	76**	135.6	139.6	11.3	33.8
KYND-FM	92.5	194	115.6	123.6	1.63	.704
KRLY-FM	93.7	194	118.6	123.6	1.74	.800
KIKK-FM	95.7	96	107.6	112.6	.489	.063
KODA-FM	99.1	194	112.6	103.6	.453	.054
KILT-FM	100.3	200	112.6	108.6	.504	.067
KLOL-FM	101.1	194	117.6	109.6	.816	.177
KMJQ-FM	102.1	200	105.6	114.6	.570	.086
KRBR-FM	104.1	192	111.6	105.6	.425	.048
KVRL-TV	Ch.26	3196	139.0	136.0	10.9	31.6

Total S

67.5

*The total effective radiation power of horizontal and vertical polarization components.

**Station was operating at a reduced power of 76 kW total power in both horizontal and vertical polarizations due to technical difficulties.

NEAR FIELD GAIN COMPRESSION $N = 12$

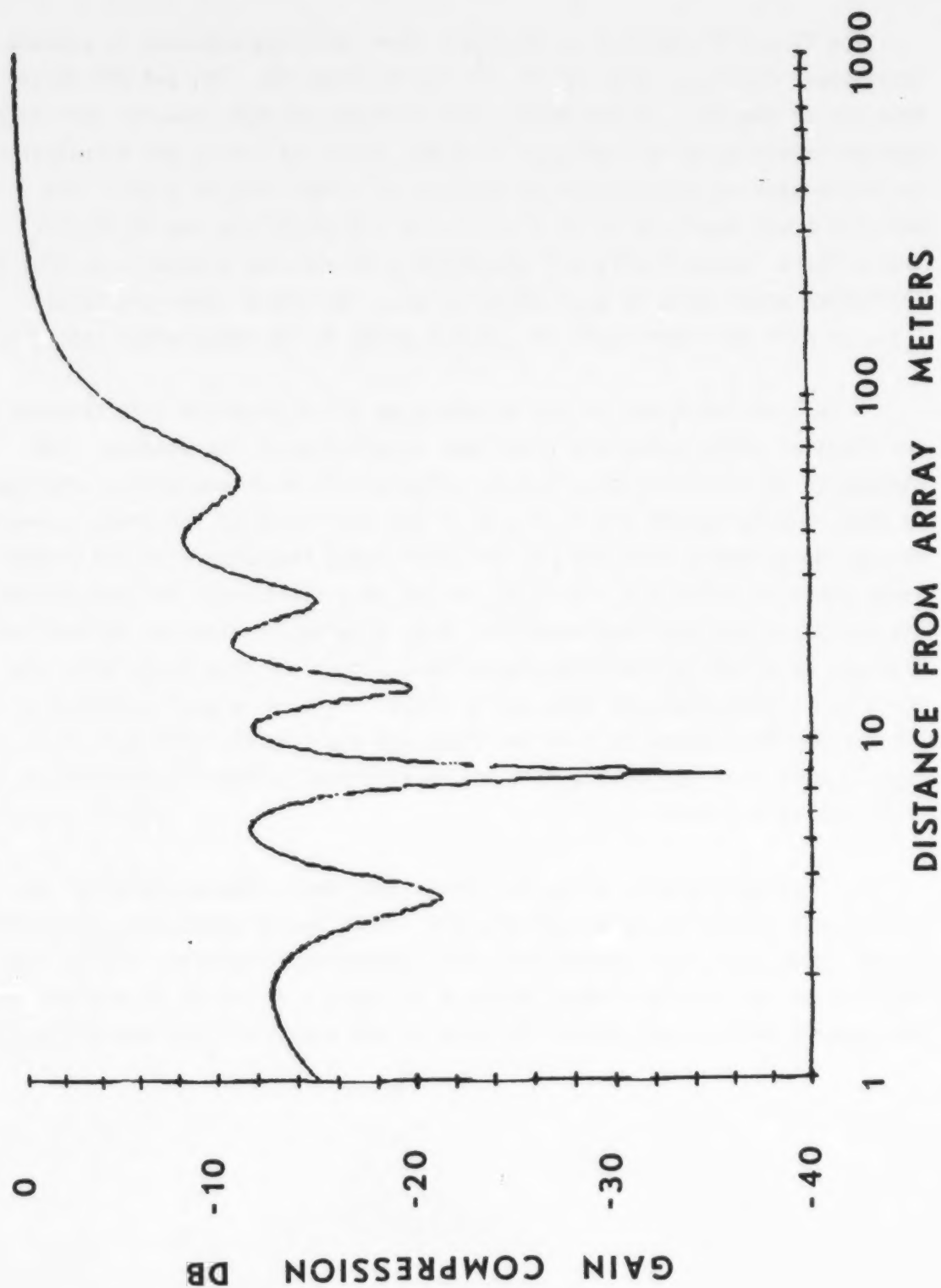


Figure 2. Near field gain compression for a 12 bay dipole array

The TV and FM stations on One Shell Tower would be expected to produce a total power density of $882 \mu\text{W}/\text{cm}^2$, $605 \mu\text{W}/\text{cm}^2$ from KVRL (26) and $277 \mu\text{W}/\text{cm}^2$ from all of the FM's, at the measurement location if that location were in the maximum intensity of the radiation patterns (both vertically and azimuthally) and there were no obstructions in the path of direct line of sight. The measured power densities of $31.6 \mu\text{W}/\text{cm}^2$ and $2.0 \mu\text{W}/\text{cm}^2$ for the TV and FM transmitters, respectively, are consistent with the real situation in that the conditions which would be expected to produce the higher power densities, i.e., on axis main beam exposures, do not exist at the measurement location.

A test was performed to try to determine the attenuation effectiveness of two kinds of solar reflective films upon application to the windows. The windows in the Milam building had no reflective films or conductive coatings on them. Using the NBS EDM-3 because of the small size of the probe's sensitive volume, measurements were made of the total field intensity with and without a large piece of reflective film taped to one of the windows. The measurements did not quantitatively determine the signal attenuation produced because the film was so effective that the signals were attenuated to a level below the EDM-3 sensitivity when the film was in place. This is in good agreement with the earlier experiences in both San Diego and New York and confirmed the feeling that solar reflective film may be effectively used to attenuate FM broadcast band signals.

A final observation, using the EDM-3, provided a demonstration of the enhancement insight of localized electric fields due to conducting structures. It was found that local fields very near conducting structures, such as the metallic leg of an office desk, could be at least a factor of 10 greater than the general ambient environment in terms of the electric field energy density.

CONCLUSIONS

These measurements confirm that there is the potential for relatively high radiofrequency field intensities to exist within the upper floors of tall buildings which are irradiated by main beam radiation from FM radio and TV broadcast antennas. Measurements of polarization components in two orthogonal planes have shown the existence of electric field intensities as great as 19 V/m in a high rise building about one block from an FM transmitter, and 10 V/m due to a TV transmitting antenna several blocks from the measurement location. No buildings were found in which the maximum exposure, the total power density from all significant signals, exceeded a value of $100 \mu\text{W}/\text{cm}^2$. Consideration of the attenuation effects of the electrically conductive film used in the Empire State Building, the shielding effectiveness of the solar film used on some windows in the Home Tower (San Diego), and the attenuation observed in the Houston test indicates that the use of electrically conductive films on windows is effective in reducing field intensities inside a building due to FM radio transmission. The use of solar reflective films appears to have the additional advantage of being a relatively inexpensive, but effective, means to reduce electric field intensities inside buildings.

The interesting effect of near field gain compression was observed in measurements in which the field intensity at distances very close to an FM antenna array were found to be significantly lower than that predicted by using the far field effective radiated power of the array. An analysis of the near field gain characteristics of the array is in agreement with the measurement. This observation is significant for estimating close-in fields from extended arrays with a large number of elements. The near-field field intensity appears to be as much as 14 dB below the value predicted on the basis of far field concepts at a distance of 26 meters for a 12 bay FM antenna.

A half-wave dipole antenna was used to sense the fields and the possible alteration of antenna calibrations because of use in an inside building environment has not been investigated. In particular, the use of a half-wave dipole in the near field of FM radio transmitting antennas should be examined from the point of view of spatial resolution of the incident electric field. The complex configuration of the fields within any reflective volume, such as the 102nd floor ESB observatory, will exhibit variations in intensity which may be unresolvable with a tuned dipole because of its physical size. It is conceivable then that certain "hot spots" might not be able to be accurately identified and measured by using tuned dipoles, at least at 100 MHz since at this frequency the wavelength is 3 meters.

It was found that various metallic objects can create intensified local fields very near them, sometimes leading to field intensities 10 times greater than the local ambient value. Additional study of this phenomenon is indicated.

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Office of Radiation Programs Technical Publications
Nonionizing Radiation

Publications of the Office of Radiation Programs are available from the National Technical Information Service (NTIS), Springfield, VA 22161. Current prices should be obtained directly from NTIS using the indicated NTIS Order number. Single copies of some of the publications listed below may also be available without charge from the Office of Radiation Programs (AW-461), 401 M St., SW Washington, DC 20460.

EPA ORP/SID 72-3	Reference Data for Radiofrequency Emission Hazard Analysis (NTIS Order No. PB 220 471)
EPA/ORP 73-2	Environmental Exposure to Nonionizing Radiation, (Available NTIS only, Order No. PB 220 851)
EPA-520/2-73-001	Nonionizing Measurement Capabilities: State and Federal Agencies (Available NTIS only, Order No. PB 226 778/AS)
EPA-520/1-74-005	RF Pulse Spectral Measurements in the Vicinity of Several ATC Radars (NTIS Order No. PB 235 733)
EPA-520/2-74-008	An Evaluation of Satellite Communication Systems as Sources of Environmental Microwave Radiation (NTIS Order No. PB 257 138/AS)
ORP/EAD 75-1	An Analysis of Broadcast Radiation Levels in Hawaii (NTIS Order No. PB 261 316/AS)
ORP/EAD-76-1	Radiation Characteristics of Traffic Radar Systems (NTIS Order No. PB 257 077/AS)
ORP/EAD-76-2	A Measurement of RF Field Intensities in the Immediate Vicinity of an FM Broadcast Station Antenna (NTIS Order No. PB 257 698/AS)
EPA-520/2-76-008	An Examination of Electric Fields Under EHV Overhead Power Transmission Lines (NTIS Order No. PB 270 613/AS)
ORP/EAD-77-2	An Investigation of Broadcast Radiation Intensities at Mt. Wilson, California (NTIS Order No. PB 275 040/AS)
ORP/EAD-77-3	An Analysis of Radar Exposure in the San Francisco Area (NTIS Order No. PB 273 188/AS)

EPA-520/2-77-008	Radiofrequency Radiation Levels and Population Exposure in Urban Areas of the Eastern United States
ORP/EAD 78-1	A Comparison of Measurement Techniques to Determine Electric Fields and Magnetic Flux Under EHV Overhead Power Transmission Lines
ORP/EAD 78-2	An Analysis of Radiofrequency and Microwave Absorption Data with Consideration of Thermal Safety Standards
ORP/EAD 78-3	Measurements of Radiofrequency Field Intensity in Buildings with Close Proximity to Broadcast Stations
ORP/EAD 78-4	Near-Field Radiation Properties of Simple Linear Antennas with Applications to Radio-frequency Hazards and Broadcasting